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DESIGN OF REDUCED ORDER LQG/LTR CONTROLLERS FOR TURRET-GUN SYSTEM

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A linear quadratic gaussian with loop transfer recovery (LQG/LTR) methodology has been applied to design robust controllers for turret-gun systems. A reduced order design procedure is presented using balanced realization reduced order models. A critical comparison is made between original and reduced order controllers. The performance of the reduced controller is satisfactory.

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INTRODUCTION

Improvements in robust performance of a turret-gun system mounted on helicopters can significantly enhance the mission capabilities of light attack helicopters. Designing a controller for such a system whose mathematical model is subject to uncertainties is an interesting and challenging problem. The uncertainties in the model may arise from unmodeled dynamics, parameter variation, linearization of nonlinear elements, etc. A significant research effort has been directed toward the design and implementation of robust controllers which can guarantee the stability and performance.

Among the various methods available for design, the linear quadratic Gaussian with loop transfer recovery (LQG/LTR) design procedure has many advantages (refs 1 and 2). This methodology will result in systems with excellent robustness, command following, disturbance rejection and noise suppression properties. The direct application of this methodology for designing controllers for turret-gun system yielded a 12/13th order controller. The convergence/numerical integration problems in the simulation of this controller along with the nonlinear plant was encountered. Hence we have employed reduced order models in designing robust controllers using LQG/LTR methodology.

A large number of procedures are available in the literature for obtaining reduced order models (ref 3). A suitable reduced order model is identified for designing reduced order robust controllers. A critical comparison of robustness properties between original and reduced order controllers is made. The residual modes neglected in the reduced order procedure may be excited by the controller to cause a destabilizing effect on the closed loop system response. This phenomenon is called spillover problem which is not present in this design procedure.

PLANT DESCRIPTION

The turret-gun system consists of an automatic cannon driven by an electrical motor and mounted within a cradle using a slide mechanism which allows for recoil movement. Recoil adapters are mounted between the recoiling mass of the gun and the cradle to absorb some of the recoil force. The cradle and gun assemblies are attached to a fork using two trunnion pins. One trunnion pin has a resolver built into it. This resolver provides the elevation pointing error to the turrent control box. The elevation axis positioning is accomplished through the use of a servovalve controlled, double acting hydraulic cylinder. The piston has unequal cross-sectional areas to account for gravitational effects. A delta hydraulic pressure transducer provides rate feedback information to the turret control box.

The fork assembly is held in place by the azimuth housing that holds a rotary hydraulic motor and a gearbox. The housing also holds a train rate sensor that measures the angular velocity of the gun/cradle/fork unit and a resolver for measuring the angular position.

The azimuth housing, fork, cradle, and gun are attached to the hull of the vehicle.

MODELING OF TURRET-GUN SYSTEM

The mathematical model of the turret-gun system contains nonlinear elements, such as gear train backlash, servovalve idiosyncrasies, hydraulic motor flows, etc. The firing disturbances excite the structural modes of the system.

Preliminary testing has shown that very little coupling exists between the elevation and azimuth axis. Therefore, the nonlinear azimuth and elevation models were developed independently. Production turret-gun systems are known to have problems mainly in the azimuth axis; therefore, this report has concentrated more on the azimuth axis.

The azimuth axis system (fig. 1) consists of three physically identifiable sections: servovalve, hydraulic motor/gearbox, and gun plant. A physical model of this system is developed by Integrated Systems Inc. (ISI). ISI has developed a detailed nonlinear model and identified various parameters of the model (ref 4). This model has been used to design full order and reduced order robust controllers.

DESIGN OF LQG/LTR CONTROLLER

The performance requirements of the controller for azimuth axis are:

- Closed loop stability under parameter variations
- Good command following performance
- Disturbance rejection
- Insensitive to modeling errors
- No spillover problems
- Sensor noise rejection

The types of uncertainties which affect the response of the system are:

- Barrel temperature
- Firing disturbance excites the structural modes of the gun
- Compliance of the system
- Helicopter motion
- Linearization of nonlinear elements

Full Order Design Results

A linearized 12th-order model of the azimuth system with motor current as input and train position as output has been derived. A typical feedback system (fig. 2) is desired to evaluate k(s) using LQG/LTR methodology. After examining the physical nonlinear model of the azimuth system, it is concluded that most of uncertainties are at the output of the plant.

By using the standard results (refs 1 and 2) a full order order LQG/LTR controller has been carried out.

The singular value plots of the target feedback loop and the open loop transfer function G(s)k(s) are shown in figure 3. The eigenvalues of the loop and closed loop system are given in table 1.

Table 1. Comparison of open loop and closed loop eigenvalues

Open loop system	Closed loop system
-1.7133×10^{-3}	$-3.396 \pm j\,82.84$, -90.519
$-5.375 \pm j\,52.04$	$-16.245 \pm j\,172.8$, -16.917 ± 89.65
$-19.819 \pm j\,294.84$	$-5852.5 \pm j\,1395.4$, $-63.58 \pm j\,135.74$
$-20.265 \pm j\,137.94$	$-4852.2 \pm j\,4543.3$, $-37.05 \pm j\,302.04$
-945.26	$-3113 \pm j\,6280.8$, -945.33
-122.23 ± 6397.9	$-1405.3 \pm j\,8136.5$, $-122.23 \pm j\,6397.9$
-1573.2 ± 4550.7	$-1573.2 \pm j\,4550.7$

Design Using Reduced Order Models

In order to minimize the computational and implementation requirements of LQG/LTR controllers, it is desirable to use reduced order models. The examination of open-loop eigenvalues of the system reveals that the system has seven dominant modes; therefore, the 7th order reduced models have been derived by using balanced realization method (ref 5). These reduced order models are employed to design LQG/LTR controllers.

The reduced controllers are implemented on the original system as shown in figure 4.

The singular value plots of the target feedback loop and the open loop transfer function $G(s)k_b(s)$ are shown in figure 5 where $K_b(s)$ is the LQG/LTR controller design using balanced realization reduced order models.

The eigenvalues of the original open loop system, reduced order model and closed loop systems with reduced order controllers are given in table 2.

Table 2. Eigenvalue comparisons

Original open loop system	Reduced order model	Closed loop system with reduced controller
-1.713×10^{-3}	-1.7133×10^{-3}	$-3.389 \pm j\,82.89$
$-5.375 \pm j\,52.04$	$-5.383 \pm j\,52.04$	-7.62
$-19.819 \pm j\,294.84$	$-19.996 \pm j\,294.56$	$-16.55 \pm j\,140.68$
$-20.265 \pm j\,137.94$	$-20.733 \pm j\,137.70$	$-16.90 \pm j\,173.47$
-945.26		$-63.02 \pm j\,310.19$
$-122.23 \pm j\,6397.9$		$-76.-7 \pm j\,57.62$
$-1573.2 \pm j\,4550.7$		$-121.92 \pm j\,6397.5$
		-624.02
		$-661.84 \pm j\,1121.7$
		$-1571.4 \pm j\,4552.9$
		-15894

The phase and gain margins of the target feedback loop and closed loop system with original and reduced order controllers are given in table 3.

Table 3. Phase and gain margins

	Margins	
	Gain (dB)	PM phase (deg)
Target feedback loop	00	69
Closed loop system with original controller	22	64
Closed loop system with reduced order controller	13	61

Simulation Results

The parameters of the system matrix are perturbed by 5% and the step responses for full order design and reduced order design are plotted in figure 6. For the same perturbation, the ramp responses were plotted in figure 7, and the step response with random disturbances at the output are given in figure 8.

CONCLUSIONS

Balance reduced order models are employed to design robust controllers using linear quadratic Gaussian with loop transfer recovery methodology for a practical turret-gun system. The eigenvalues and stability margins of the reduced order design are compared with the original controller. These comparisons and simulation results indicate that the reduced order design gave satisfactory results. The spillover problems are not present in this reduced order controller. The main advantage of the reduced order design is the simplification in implementation.

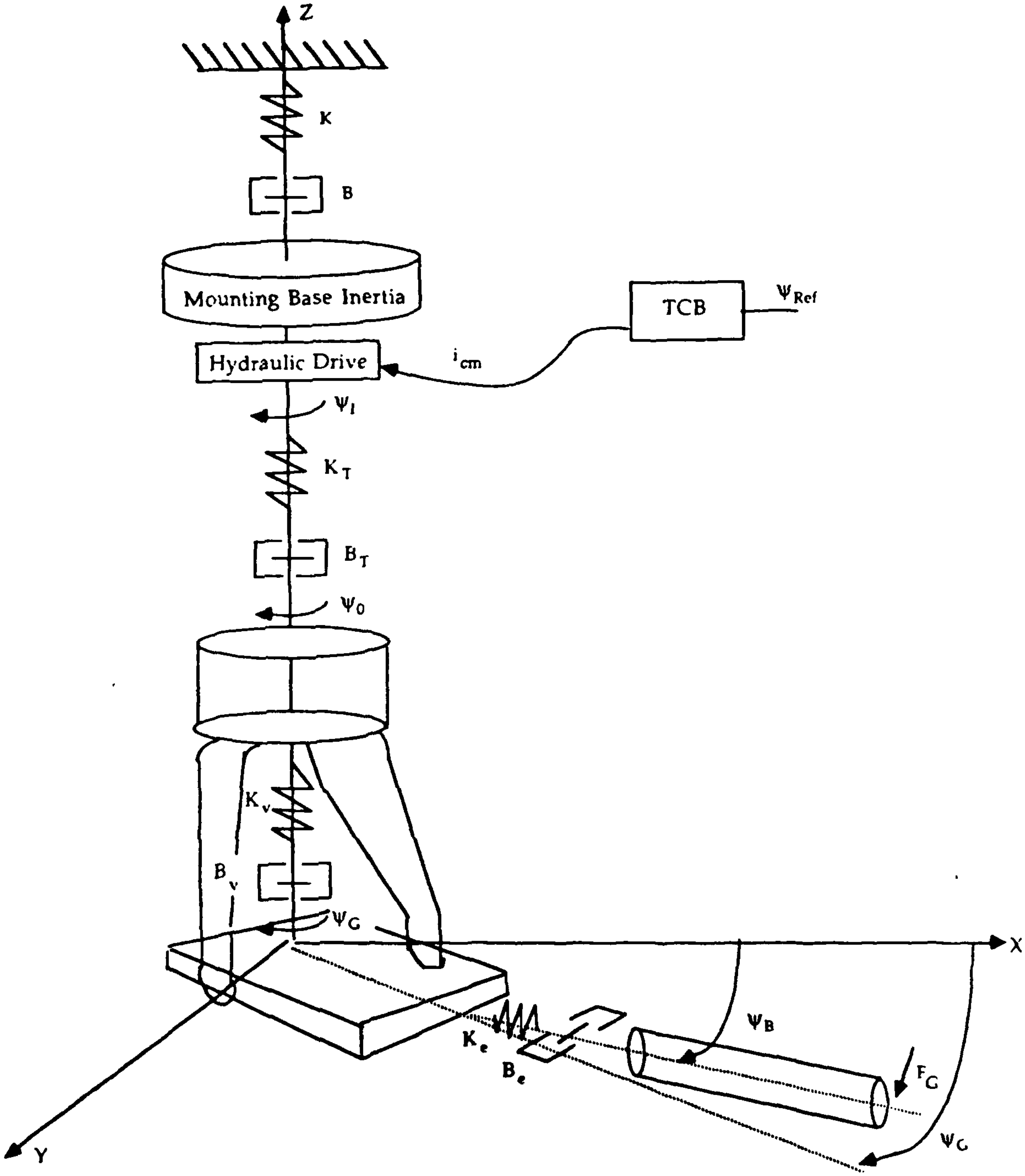

Figure 1. Azimuth axis system

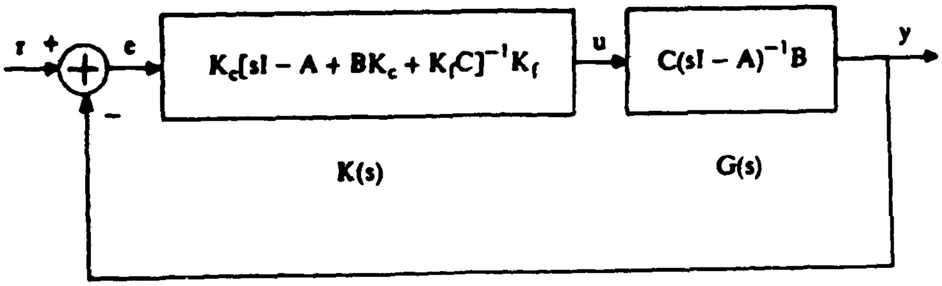

Figure 2. Closed loop system

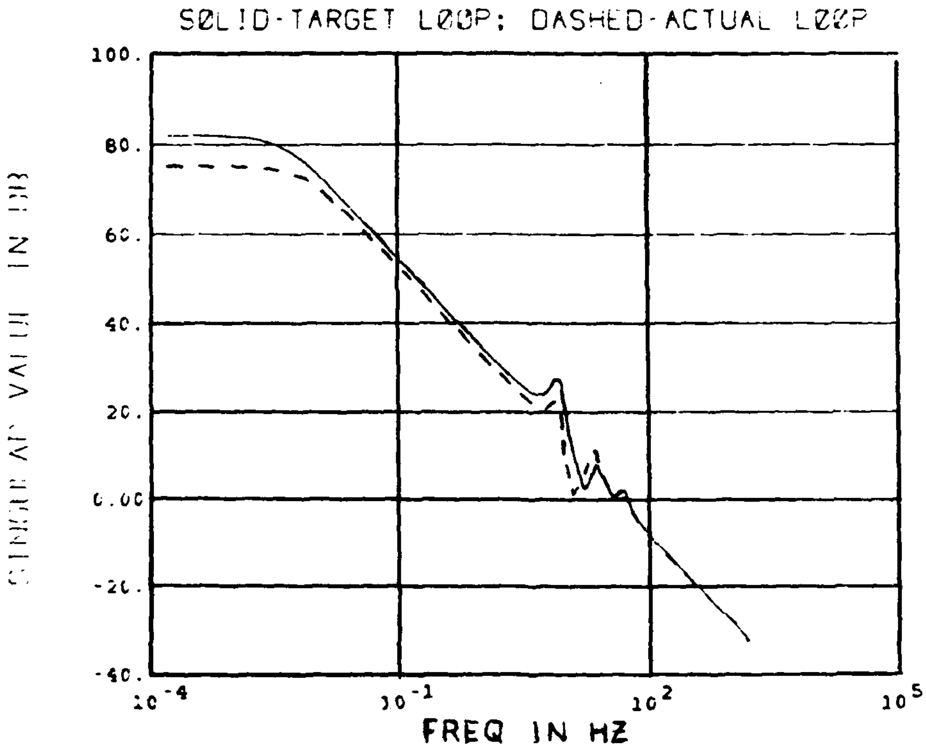

Figure 3. Singular value plots of TFL and G(s)k(s)

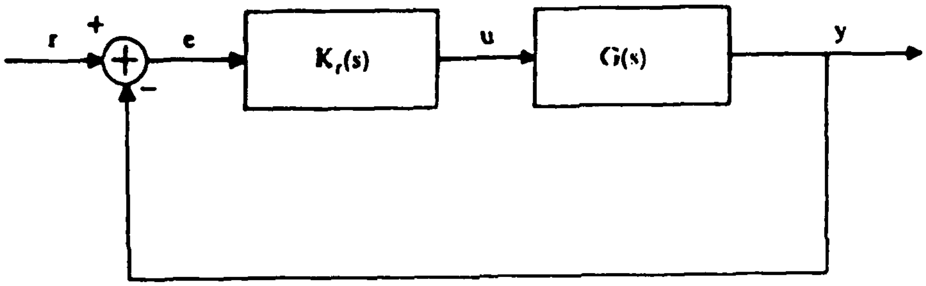

Figure 4. Implementation of reduced order controller

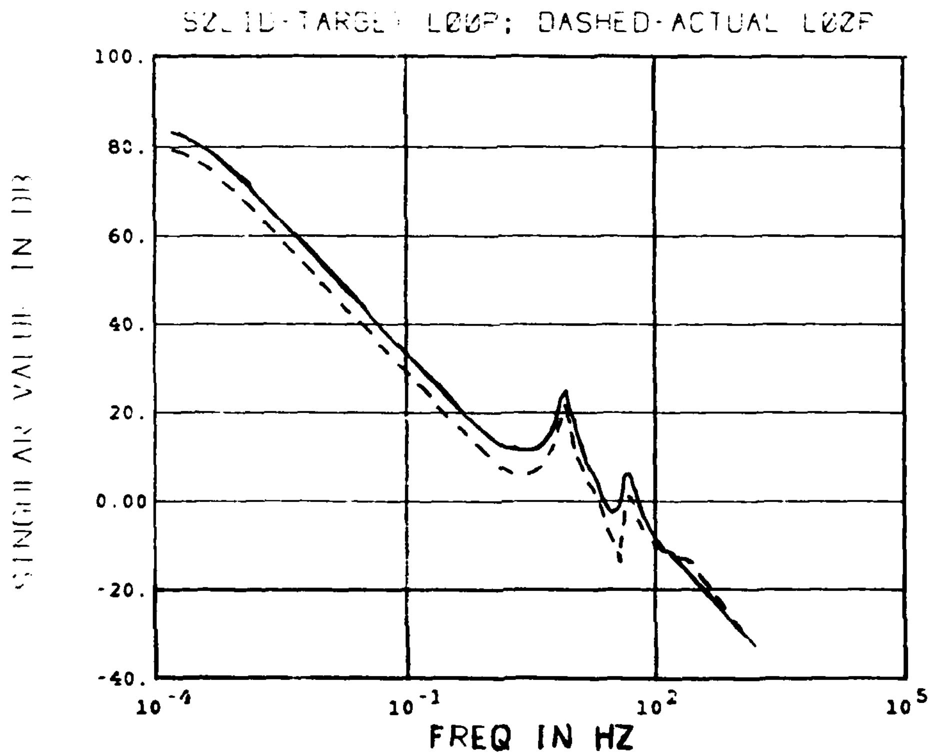

Figure 5. Singular value plots of TFL and $G_b(s)k_b(s)$

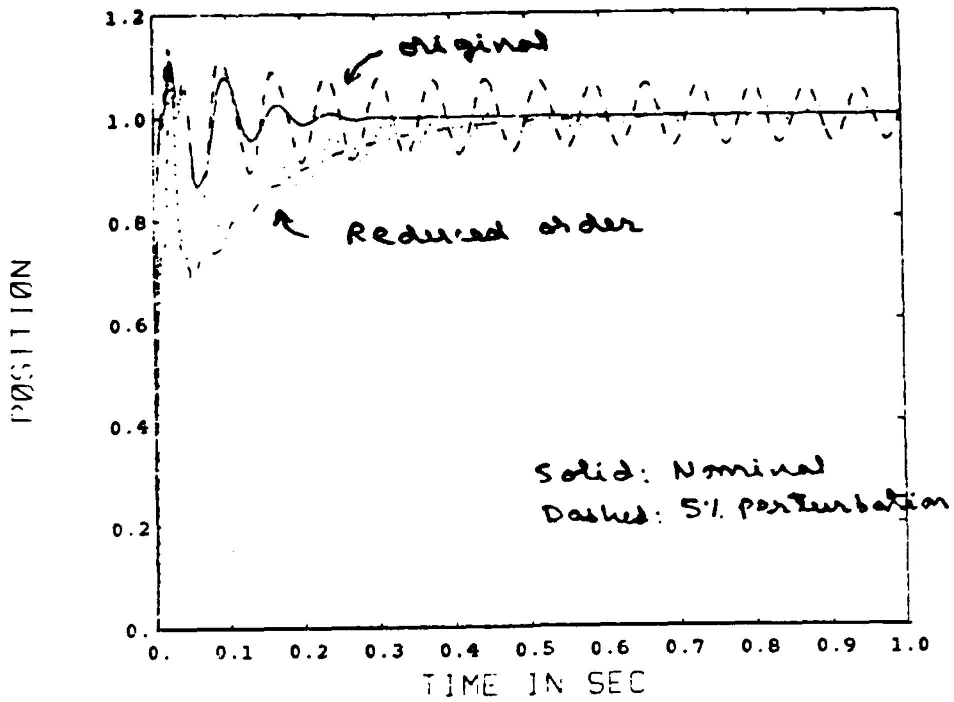

Figure 6. Step response

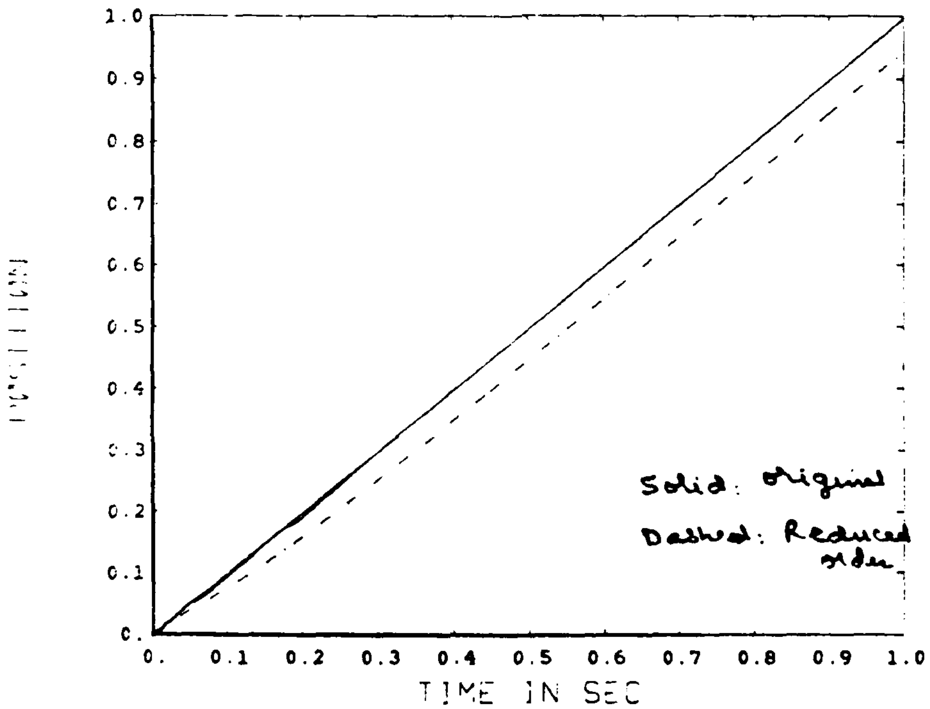

Figure 7. Ramp response

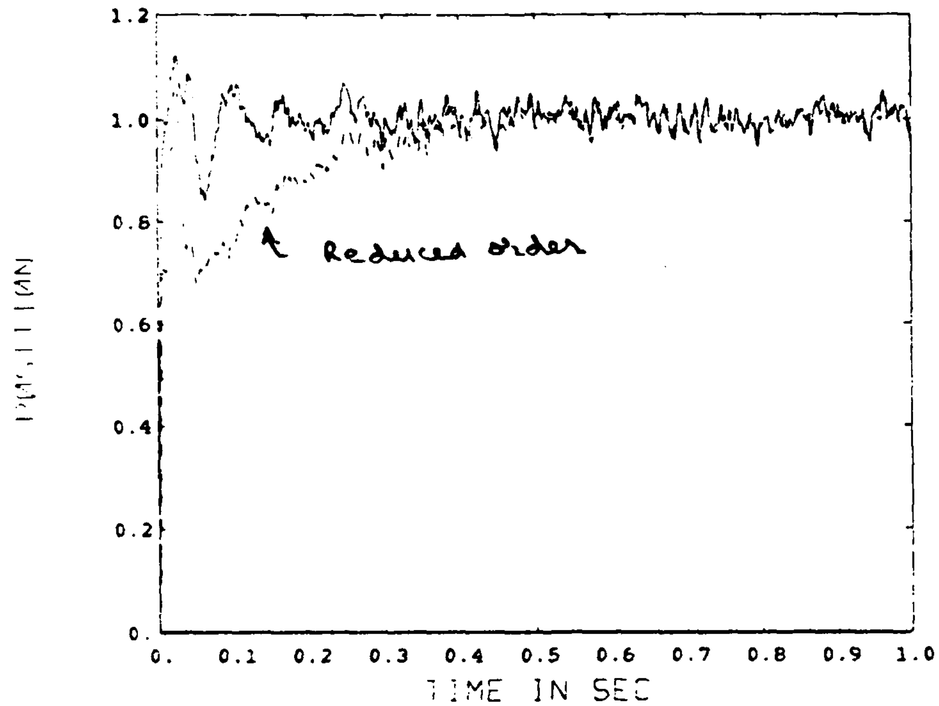

Figure 8. Step response with disturbance

REFERENCES

1. Athans, M., "A Tutorial on the LQG/LTR Method," Proceedings of American Control Conference, Seattle, pp 1289-1296, June 1986.

2. Athans, M. and Stein, G., "The LQG/LTR Procedure for Multivariable Feedback Control Design," IEEE Trans. on Automatic Control, vol AC-32, no. 2, pp 105-114, February 1987.

3. Bonvin, D. and Mellichamp, D. A., "A Unified Derivation and Critical Review of Model Approaches to Model Reduction," International Journal of Control, 1982, vol 35, no. 5, pp 829.848.

4. Shah, S., "Gun/Turret Adaptive Controller for Integrated Air-to-Air Weapon Systems," Report No. 127, Integrated Systems Inc., California, July 1988.

5. Moore, B. C., "Principal Component Analysis in Linear Systems: Controllability, Observability, and Model Reduction," IEEE Trans. Automatic Control, vol AC-26, no. 1, pp 17-31, February 1981.

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